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MEMORANDUM

TO: Olympic Elwha Project Team Leader, Elwha River Restoration Project, Olympic National Park, National Park Service, U.S. Department of the Interior, 826 East Front Street, Suite A, Port Angeles, WA 98362
Attention: Dr. Brian Winter

FROM: Timothy J. Randle, Hydraulic Engineer
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SUBJECT: Application of the Report Entitled: "Sediment Analysis and Modeling of the River Erosion Alternative", Elwha Technical Series PN-95-9, Randle, Young, Melena, and Ouellette, U.S. Bureau of Reclamation, October 1996

The purpose of this memorandum is to provide guidance on how to apply results from the subject report to a new hydraulic model that uses 2001 survey data of the Elwha River and flood plains in the 5-mile reach between Elwha Dam and the mouth.

Overview of Sediment Modeling

The October 1996 sediment modeling and analysis report was prepared in support of the draft and final environmental impact statement for the "Elwha River Ecosystem Restoration Implementation" (Olympic National Park, April and November, 1996). The modeling and analysis report documented predictions of how much reservoir sediment would be eroded from Lake Mills and Lake Aldwell during concurrent removal of Glines Canyon and Elwha Dams. The report also provides predictions on how this eroded sediment would be transported and deposited along the downstream river channel and how sediment deposition (aggradation) would increase water surface elevations during a possible 100-year flood over a short- and long-term timeframe.

Reservoir Erosion Model Results

U.S. Bureau of Reclamation (Reclamation), in cooperation with the National Park Service, created a new reservoir-sediment-erosion model for the Elwha River Restoration Project. This model predicted that between 15 and 32 percent of the 8.50 million yd^3 of coarse sediment (sand, gravel, and cobbles) would be eroded from the two reservoirs over a 3-year period during and immediately following dam removal. The model also predicted that between 53 and 61 percent of the 9.21 million yd^3 of fine sediment (clay and silt) would be eroded from the two reservoirs during the same 3-year period. The report concluded that remaining reservoir sediment would become stable and remain in the two reservoirs over the long-term. Recent updates and refinements to the reservoir erosion model in 2002 have resulted in slight revisions to the predicted volume of sediment being delivered to the downstream river channel. New model results predict that between 23 and 31 percent of the coarse sediment and between 50 and 60 percent of the fine sediment would be eroded from the reservoirs over a 13-year period during and immediately following dam removal (see table 1). Vegetation is expected to colonize and stabilize the remaining reservoir sediment within 3 to 5 years following dam removal.

Table 1. Reservoir Sediment Erosion Summary Using Four Hydrologic Periods

		Predicted Reservoir Sediment Erosion					
1994 Reservoir Sediment Volumes (yd^3)		1950 to 1963	1968 to 1981	1971 to 1984	1989 to 2002	Minimum	Maximum
Total Lake Mills Sediment	13,830,000	35%	39%	37%	34%	34%	39%
½ Sand & Gravel	7,210,000	14%	20%	16%	23%	14%	23%
½ Silt & Clay	6,620,000	58%	60%	60%	46%	46%	60%
Total Lake Aldwell Sediment	3,880,000	63%	63%	63%	64%	63%	64%
1/3 Sand & Gravel	1,290,000	71%	71%	72%	73%	71%	73%
2/3 Silt & Clay	2,590,000	59%	59%	59%	60%	59%	60%
Total Reservoir Sediment	17,710,000	41%	45%	43%	41%	41%	45%
Sand & Gravel	8,500,000	23%	28%	25%	31%	23%	31%
Silt & Clay	9,210,000	58%	60%	60%	50%	50%	60%
		Predicted Reservoir Sediment Erosion Volumes (yd^3)					
1994 Reservoir Sediment Volumes (yd^3)		1950 to 1963	1968 to 1981	1971 to 1984	1989 to 2002	Minimum	Maximum
Total Lake Mills Sediment	13,830,000	4,830,000	5,440,000	5,120,000	4,710,000	4,710,000	5,440,000
½ Sand & Gravel	7,210,000	1,010,000	1,460,000	1,160,000	1,660,000	1,010,000	1,660,000
½ Silt & Clay	6,620,000	3,820,000	3,980,000	3,960,000	3,050,000	3,050,000	3,980,000
Total Lake Aldwell Sediment	3,880,000	2,440,000	2,460,000	2,460,000	2,480,000	2,440,000	2,480,000
1/3 Sand & Gravel	1,290,000	910,000	920,000	930,000	940,000	910,000	940,000
2/3 Silt & Clay	2,590,000	1,530,000	1,540,000	1,530,000	1,540,000	1,530,000	1,540,000
Total Reservoir Sediment	17,710,000	7,270,000	7,900,000	7,580,000	7,190,000	7,190,000	7,900,000
Sand & Gravel	8,500,000	1,920,000	2,380,000	2,090,000	2,600,000	1,920,000	2,600,000
Silt & Clay	9,210,000	5,350,000	5,520,000	5,490,000	4,590,000	4,590,000	5,520,000

The reservoir sediment erosion model results are based on the simulation of four separate hydrologic periods:

- 1950 – 1963 represents a dam removal period that begins with one year of relatively high annual peak discharge, followed a year of relatively low, and then a year of moderate peak discharge.
- 1968 – 1981 represents a dam removal period that begins with the lowest peak discharges for any three consecutive water years of record.
- 1971 – 1984 represents a dam removal period that begins with progressively higher annual peak discharges in each of the first three years.
- 1989 – 2002 represents a dam removal period that begins with the highest peak discharges for any three consecutive water years of record.

The reservoir sediment erosion model predicted that the river would erode a channel (of a certain width) completely through the sediment of each reservoir. To be conservative, the minimum width of the erosion channel through each reservoir was computed using an empirically based equation developed for the widest reach of the Elwha River. The width of this erosion channel would be between 630 and 1,500 feet wide with the greater width being at the higher elevations. A relatively small percentage of the coarse sediment would be eroded (23 to 31 percent) because the coarse sediment is presently in the delta at the upstream end of the reservoir. This sediment would be eroded and redeposited across the reservoir during progressive increments of dam removal and much of it remaining along the margins of the reservoir.

HEC-6 Model Application

The volume of fine sediment predicted to erode from the reservoirs was assumed to be transported in suspension (without deposition) all the way to the Strait of Juan de Fuca. The Army Corps of Engineers, HEC-6 sediment transport model was applied to predict how much of the eroded coarse sediment would deposit and aggrade the riverbed downstream of Elwha Dam over both the short- and long-term (3 and 53 years following the start of dam removal). All of the coarse sediment eroded from Lake Mills was assumed to be transported to Lake Aldwell without deposition in the middle reach between the two reservoirs. The HEC-6 model used a total of 29 cross sections to represent the 5-mile reach of the Elwha River between the mouth and Elwha Dam. Of these 29 cross sections, 20 sections were surveyed in 1994, 8 sections were duplicated from a portion of the surveyed sections, and a wide, shallow, rectangular cross section was added to represent the river mouth. These 29 cross sections were the best available data at the time and tended to represent the average slope of the riverbed. However, they did not fully define localized changes in slope caused by the series of pools and riffles that form the lower Elwha River channel. The series of river pools between Elwha Dam and the river mouth could contain 500,000 yd^3 of sediment during periods of low flow.

HEC-6 Model Results

Between river miles 0 (Elwha River mouth) and 4.04 (downstream end of bedrock canyon), the HEC-6 model predicted that the riverbed would aggrade between 0 and 10 feet (with an average of 2.7 feet) over the short term (3 years) (see table 2 and figure 1). The greatest amount of aggradation predicted was along reaches with flatter slopes where cross sections were duplicated. The model also predicted that this short-term aggradation from erosion of reservoir sediments would increase the 100-year flood stage by an average of 0.7 feet. Over the long-term (53 years), the model predicted that the riverbed would continue to aggrade from the restoration of the natural upstream sediment supply, and that the average aggradation would reach 4.6 feet. This long-term aggradation was predicted to increase the 100-year flood stage by an average of 2.5 feet.

In reality, the erosion and release of coarse sediment from the reservoirs is expected to successively aggrade river pools in a downstream progression over the short term. The water surface profile would only significantly increase if there were significant aggradation on the riffles, which have steeper slope, higher river velocity, and higher sediment-transport capacity than river pools. If coarse sediment did aggrade the riffles, then river flows would begin to enter and widen secondary river channels. Thus, the river channel would tend to migrate laterally by occupying and eroding the banks and vegetation of old river channels. This means that the river channel would move laterally if the amount of aggradation became too much in any one location. As the sediment loads increase and the channel bed aggrades, the river channel would tend to flow in a straight and braided pattern.

Over the long-term, the Elwha River would likely reach a new equilibrium similar to that of the predam river. Aggradation over the long-term would only occur if the river channel were aggrading prior to the construction of Elwha Dam. Geomorphic evidence should be available if such aggradation was occurring, but no such evidence is available.

The HEC-6 model is limited to predicting vertical aggradation of a stationary river channel and flood plain. The model cannot simulate the straightening of the river channel, the lateral movement of the river channel, nor the bank erosion of secondary channels. Although short-term aggradation may increase the 100-year flood stage by more than the amount predicted by the HEC-6 model, the long-term average increase that was predicted by the HEC-6 model (2.5 feet) provides a useful upper limit.

As a check on this upper aggradation limit, the maximum coarse sediment erosion volume (2.6 million yd^3, see table 1) was assumed to deposit evenly over the channel migration zone area (30 million ft^2) downstream of Elwha Dam to the mouth (see figure 2). The average thickness of such aggradation is 2.4 feet. This calculation assumes that none of the coarse sediment eroded from Lake Mills is deposited along the river channel between the two reservoirs, nor makes it to the Strait of Juan de Fuca.

These conservative assumptions provide another check on the upper aggradation limit and agree quite closely with the HEC-6 model results for the long-term condition.

Table 2. HEC-6 Short-term and Long-term Model Results: Differences from Initial Conditions

Elwha Dam to Strait of Juan de Fuca		100-year flood water surface elevation: difference from initial conditions (ft)			Thalweg Elevations (ft)		
Cross section	River Mile	Initial Elevation (ft)	1971-74 Short-term	1919-70 Long-term	Initial thalweg elevation	Aggradation (+) Degradation (-)	
						Short-term	Long-term
0	0.00	10.1	0.0	0.0	-1.0	3.7	2.8
1	0.38	12.1	2.0	2.0	0.6	0.0	-0.1
2	0.78	19.4	0.5	3.4	9.2	1.4	5.7
4	1.03	24.8	0.4	4.2	13.0	0.9	7.8
5	1.28	31.3	1.0	5.5	21.5	1.7	6.7
6	1.44	34.2	0.4	4.6	21.2	1.5	8.3
7	1.68	39.1	-0.1	3.7	26.6	-0.1	6.0
8	1.92	42.6	0.1	2.1	31.5	-0.1	4.2
9	2.20	47.5	-0.2	3.2	34.9	-0.1	3.4
10	2.50	52.2	0.1	0.8	36.6	-0.1	3.9
11	2.79	56.0	0.5	3.1	42.3	-0.1	3.6
12	2.90	61.6	0.1	1.1	43.0	-0.1	4.6
13	3.10	67.3	0.8	3.1	51.2	3.2	4.6
14	3.24	68.4	1.2	4.9	59.2	1.2	2.2
15	3.29	70.6	1.8	3.9	54.3	6.2	7.5
15A	3.40	75.5	2.0	3.3	54.3	8.5	9.6
16A	3.45	76.2	1.4	3.0	62.5	2.5	3.4
16	3.47	80.4	0.8	1.7	60.6	4.2	4.5
18	3.49	79.8	0.6	1.8	56.9	5.9	5.7
19	3.58	80.8	2.7	3.4	56.2	8.8	6.5
20A	3.68	84.8	-0.1	0.1	72.4	0.0	0.0
20B	3.69	90.2	-0.2	-0.3	69.8	1.4	1.2
20	3.83	90.9	0.0	-0.1	69.8	5.0	2.3
20C	4.04	91.8	1.0	0.8	69.8	10.1	5.2
20D	4.23	92.4	3.1	2.3	75.3	9.2	2.0
20E	4.46	95.0	7.3	5.8	75.3	12.2	2.9
21A	4.84	108.4	12.7	12.6	93.7	-0.1	-0.1
21	4.86	112.3	19.8	19.6	84.8	6.1	7.9
22	4.92	114.9	16.0	16.2	66.8	26.5	25.5
River Miles 0 to 4.04							
Minimum			-0.2	-0.3		-0.1	-0.1
Maximum			2.7	5.5		10.1	9.6
Average			0.7	2.5		2.7	4.6

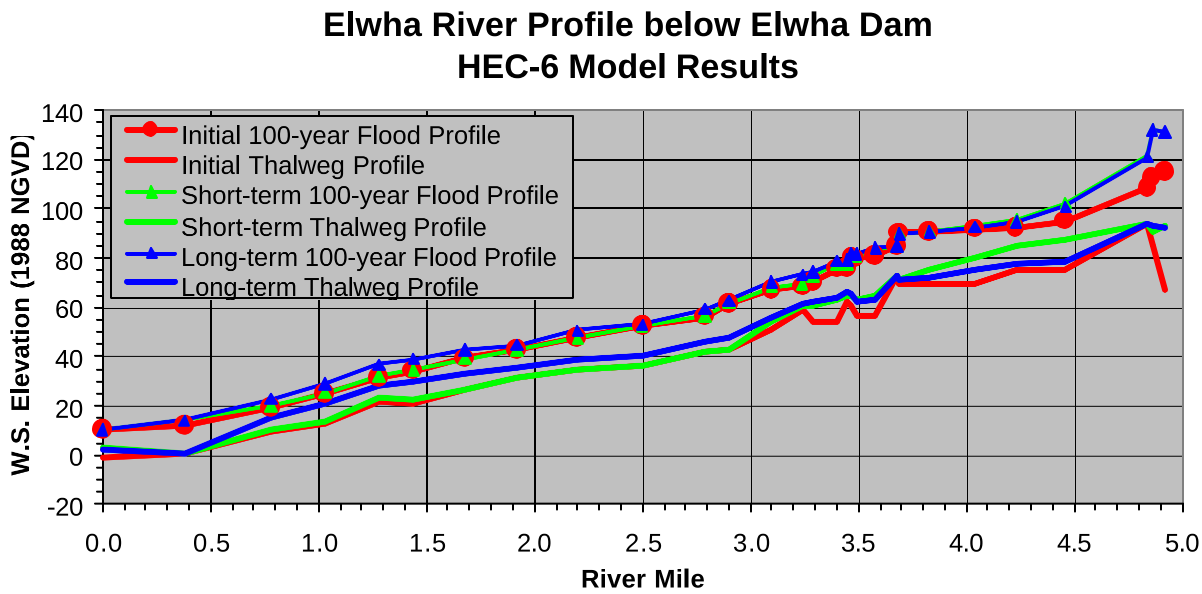

Figure 1. Longitudinal River Profile of HEC-6 Model Results.

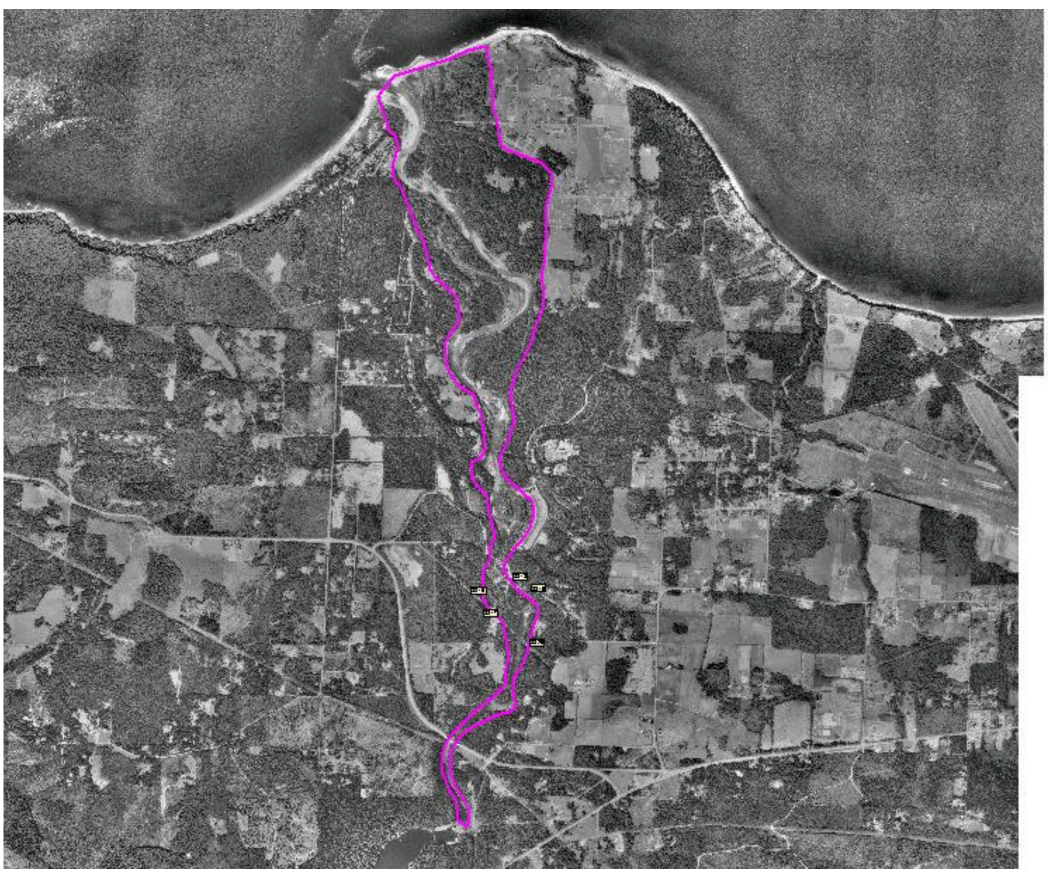

Figure 2. Channel migration zone boundaries for the Elwha River below Elwha Dam.

New Survey and Hydraulic Model

During the winter and spring of 2001, new surveys were conducted to more precisely define the topography of the river channel and flood plains (Washington North State Plane Coordinates, 1983 North American Datum and 1988 National Geodetic Vertical Datum). During February 2001, a LIDAR survey was conducted to measure the topography of the flood plains and terraces. During April and May of 2001, the river channel bottom was surveyed by raft using a depth sounder and survey-grade GPS equipment. These data sets were combined to provide a digital elevation model of the river channel, flood plains, and terraces. From this combined data set, the U.S. Army Corps of Engineers has constructed 135 cross sections of the Elwha River for use in the HEC-RAS hydraulic model of the river channel and flood plains, downstream from Elwha Dam.

Application of HEC-6 Sediment Model Results to New HEC-RAS Hydraulic Model for River Channel Downstream of Elwha Dam

A longitudinal profile of channel bottom and 100-year water surface elevation was generated from Elwha Dam to the mouth to compare the HEC-6 and HEC-RAS model results (figures 3 and 4). In some locations, the HEC-6 predicted 100-year water surface elevation for the short- and long-term conditions is less than the present water surface elevation predicted by the HEC-RAS model. This is because the new data used in the HEC-RAS model captures more of the hydraulic controls (riffles and rapids) and assumes higher roughness coefficients than the HEC-6 model.

The HEC-6 model results should be used to estimate the average increase in the 100-year flood stage over the short-term period representing dam removal and the first few years following dam removal. The average increase in the 100-year flood stage (0.7 feet for short-term and 2.5 feet for long-term) should be uniformly applied to the final results from the HEC-RAS model. Any attempts to utilize site-specific results from the HEC-6 model results would require more precision than the model is capable of providing. The only other choice would be to conduct a second round of sediment transport modeling, but a model that could simulate more physical processes than HEC-6 would be required. Additional sediment transport modeling could be an expensive and time-consuming task (at least $200,000 and 1-2 years to complete) that may not yield much better information.

Conclusions

The HEC-6 modeling results provide information on potential increases in flood elevations that might occur as a result of riverbed aggradation. Conceptually, short-term aggradation is expected to be greater than long-term permanent aggradation. The HEC-6 model results for the long-term provide an upper limit to the flood stage increase (2.5 feet) caused by short-term aggradation. Therefore, a maximum increase in the existing HEC-RAS water surface profiles of 2.5 feet can be compared with the existing levee elevations to determine if and where the levee height needs to be increased. However, extensive channel migration would have to occur before this maximum amount of aggradation could occur. Therefore, the greatest threat to the levees is most likely from the direct erosion by river velocities when the main river channel migrates adjacent to portions of the levees. The actual amount of riverbed aggradation can be controlled by controlling the rate of dam removal. The monitoring plan has been designed in insure that aggradation would not result in an increase in the 100-year flood stage of more than 2.0 feet.

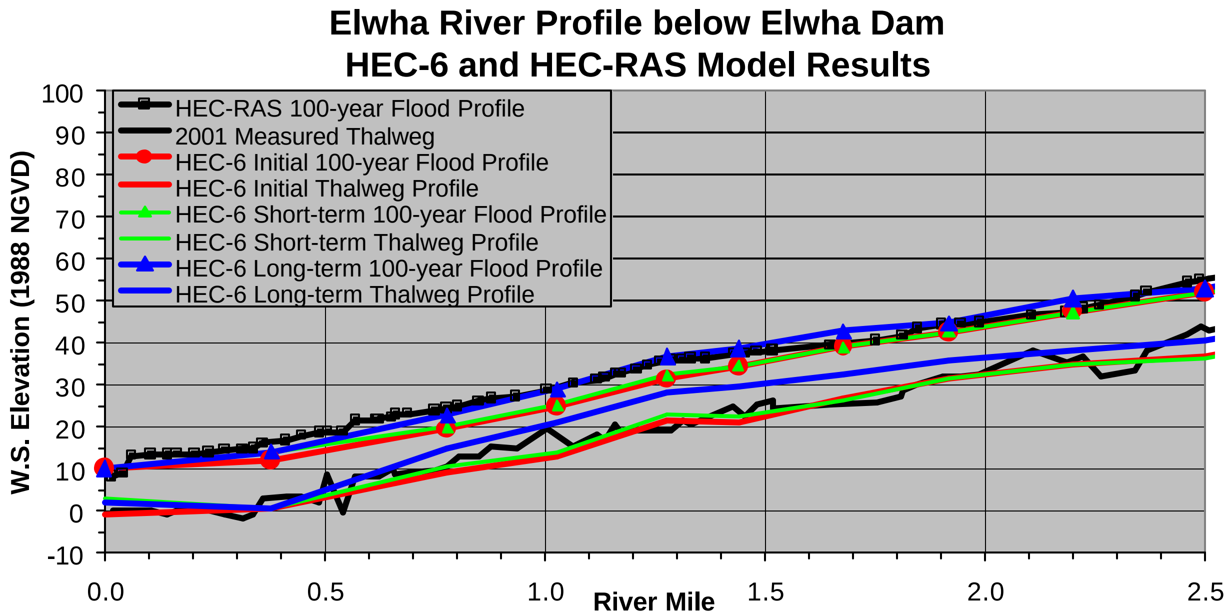

Figure 3. Comparison of HEC-6 and HEC-RAS model results for the reach between river miles 0 and 2.5.

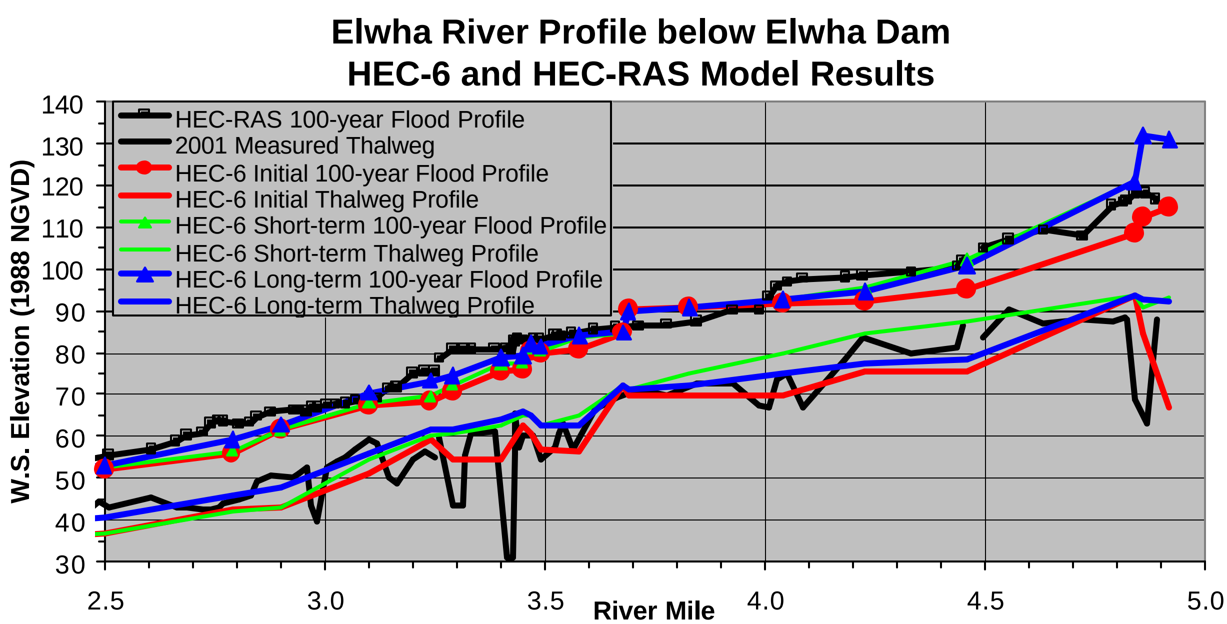

Figure 4. Comparison of HEC-6 and HEC-RAS model results for the reach between river miles 2.5 and 5.

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